METHODOLOGICAL DESIGN FOR FLOOD RISK ASSESSMENT AT A LOCAL LEVEL USING SCARCE INFORMATION

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ABSTRACT: Floods are the most frequent natural events in Colombia, recognized as the “socio-natural” threat that has most affected the country´s history, taking into account their high frequency, the large territorial areas involved and the amount of population that is affected. This paper shows the advances in the research that aims to provide the analytical and methodological tools necessary to strengthen the local territorial development processes. A methodology that can be applied and trusted, as the country has data, knowledge, and experiences, all limited by their conditions of quality and quantity. The methods used to perform each of the involved steps within the risk evaluation process, that is, the knowledge of the territory, analysis of the threat, and evaluation of the vulnerability, involve the investigation-action; the analysis of the document sources, historical archives, and databases; the performance of semi-structured interviews of experts and interest groups, surveys of homes, validation interviews, workshops, teledetection, geographic information systems-GIS analysis and census data. The research shows how the methodology can be applied by using two Colombian study cases and how it is possible to include it in the formulation of structured public action policies at local level, in the correction of medium and long term situations of vulnerability, in the construction of risk reduction scenarios and in other activities of territorial and environmental planning.

Key Words: Flood Management, Flood Risk, Urban Centers, Territorial and Environmental Planning.

1. INTRODUCTION

One can use the information from international statistics, such as the EM-DAT database, supplied by (Centre for Research on the Epidemiology of Disasters-CRED 2013) to determine that in Colombia, floods can be found in the first place among the 10 major natural disasters in the period between 1900 and 2012 because of the number of people affected, and in the second place due to the amount of economic losses. Also, until 2012, Colombia occupied the tenth and eighth place worldwide when measuring the number of deaths and damages respectively, generated by hydrological disasters (Brakenridge 2011; Guha-Sapir, Vos, and Below 2012).

There exists a growing trend in the number of flood events, especially in the last 20 years. Records of recent floods in the years 1970, 2004, 2005, 2007, 2007, 2008, 2010, and 2011 can be found in the EM-DAT database, with the most severe in terms of number of deaths occurring in the months of April 2010 and November 1970 - 418 and 307 dead respectively (Centre for Research on the Epidemiology of Disasters-CRED 2013). In terms of costs/damage generated by the flood, it states that the floods occurring in the years 2010-2011 have been the most catastrophic due to the large losses of property, homes, crops and other livelihood, and the impact on the vital infrastructure such as schools, hospitals, and roads.

The main socio-economic, ecological, and environmental impacts happened especially in urban zones as a result of inadequate human activity, among them, unplanned growth and the pressure on the environment due mainly to the progressive wear of the watersheds and the beds of rivers and creeks, the clogging of natural drainages limiting wetlands, the increase of erosion processes caused by deforestation and burning, the occupation of the water rounds, etc.

Colombia is now subject to a massive forced displacement process, where approximately 74% of the population is inhabiting urban zones with a tendency to increase, since they are considered the nucleus of opportunity and the source of economic, social, and political development. Many of these zones with less than 500000 inhabitants have started as a product of decentralization and the displacement processes due to the conflict, making their leaders incapable of self-financing, as they lack the human, institutional, and economic resources for good governance.

Urban growth has brought about new opportunities for development, but also the conglomeration of poverty and inequality conditions, and of problems associated with the inadequate planning and definition of urban policies, which results in their unsustainable growth and an increase in the degree of vulnerability.

The last report “State of the Cities of Latin America and the Caribbean” of the (Programa de las Naciones Unidas para los Asentamientos Humanos 2012) states that more than 80% of the records of losses related to disasters occurred in urban zones, and even though there are variations according to the countries, between 40 and 70% occurred in cities of less than 100000 inhabitants. That is, everything points to a larger risk in rapidly growing smaller and medium sized urban centers than in larger cities or rural zones, which can be related to the risk management and investment ability that tends to be weaker in smaller cities.

In this context, the research question that must be considered is the following: ¿Is it possible to establish a flood risk evaluation methodology at a local level for the context of small and medium urban centers, under conditions of information limited in its quantity and quality, by analyzing physical-natural factors and identifying global vulnerability factors?.

A detailed study of the flood risk in conditions of limited quality and quantity information is conducted for two Colombian study cases, with the purpose of establishing a risk evaluation methodology at a local level that contains the necessary analytical and methodological tools and strengthens the local risk management, development planning, and land processes.

The two selected case studies are in the urban zones of the municipalities of Caucasia (Antioquia) and El Plato (Magdalena), see Figure 1. The first has a population in its urban municipal head of 82481 inhabitants (Alcaldía de Caucasia, 2013) and the second of 40521 inhabitants (Departamento Administrativo Nacional de Estadística-DANE 2011).

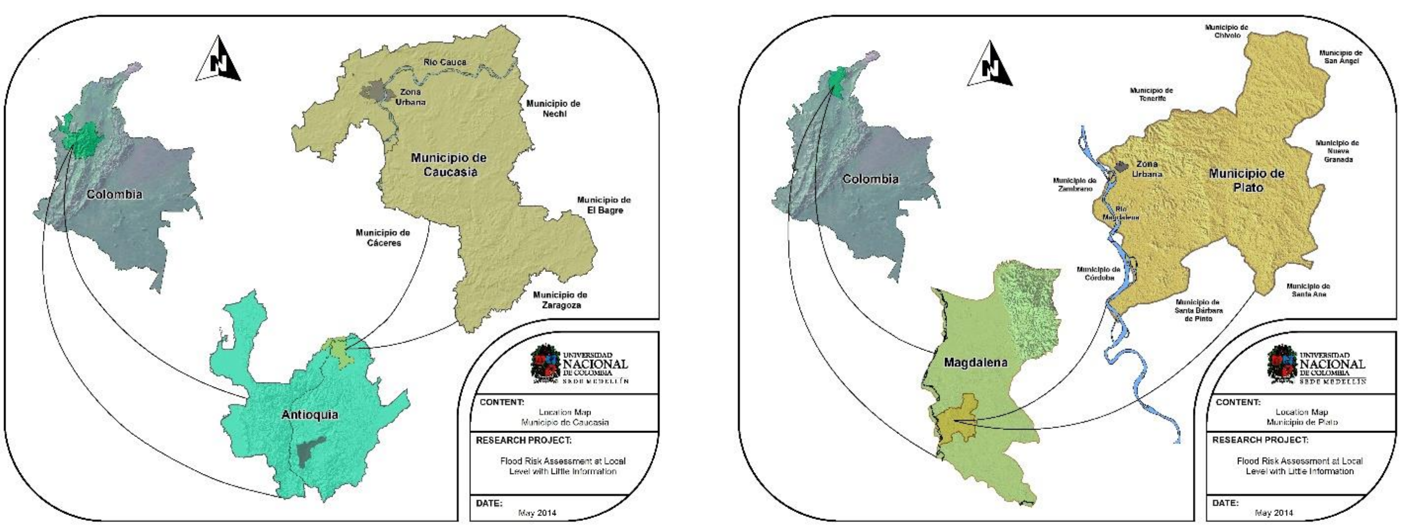

Figure 1: Location of the study zones

Both municipalities have records of disasters in their urban zones, especially periodic floods caused by the Cauca River for the Caucasia Municipality and the Magdalena River for the Plato Municipality. In addition, both present difficulties in land planning, don't have early warning systems, nor the adequate infrastructure to prevent and/or mitigate these threats. Their existing land occupation patterns are related to the increase in population, informality and the lack of access to safe places that heighten the conditions of vulnerability of the population.

2. URBAN RISK AND METHODS FOR ITS EVALUATION

An adequate urban risk management can be a difficult task to achieve in municipal environments that suffer from both the lack of technical capacity and financing resources, but it is possible to have more success with a larger participation and a change in the traditional management methods (Jha, Bloch, and Lamond 2012).

It is fundamental to identify the information, the experience and the method that the different interest groups can offer and to propose management actions under their different perspective, contexts, experience, and knowledge. The decision makers, especially at the local and regional level, need to know clearly what is happening in each context and especially during the processes that intervene when there is a threat such as a flood, so they can choose the best alternatives, methods, tools, and required costs to make the best management decisions.

The risk assessment process is the operative base of a culture of prevention, and the necessary and fundamental process in any strategy that has as its objective to safeguard the life and goods of a community as a function of consolidating territories, programs, projects, and strategies that are resilient when faced with adverse or crisis situations. It must be taken into account for the formulation and execution of public or private investment projects, whether in progress or planning stages, for the elaboration of local development plans, of land management plans, environmental management plans, productive activities and the management of natural resources and of risk management plans (Dirección de Gestión del Riesgo 2010; Dirección Nacional de Planeación 2010; Ministerio de Ambiente Vivienda y Desarrollo 2005; Narváez, Lavell, and Pérez 2009; Olivera 2007).

Therefore, such an evaluation constitutes the main instrument for planning or improving development actions, since the more precise the analysis, the more efficient the assignment of resources and more accurate the measures that are adopted for its reduction.

The most important steps of the risk evaluation process are:

2.1 Knowledge of the territory

The detailed knowledge of the conditions and realities of the territory are the base of an effective and realistic analysis of the disaster risks (Marquínez, Lastra, and Fernández 2006). In our case, there is not enough detailed information and adequate technical scale cartography, so a consolidation of information process and creation of a geographic information system for the territory subject to analysis has been undertaken (Marco Segura 2006).

2.2 Analysis of flood threat

Its objective is to know the nature, probability, intensity, and spatial distribution within a zone of one or several floods during determined time periods as to establish an estimate of the damage they can cause. Several methodologies and tools for the flood threat analysis have been reviewed by contrasting them with the availability of information in the selected case studies, where historical, geomorphological, and hydrological-hydraulic methods and those assisted by remote sensors and GIS could be adapted and combined (Arrighi et al. 2013; Benito 2006; Diez-Herrero, Lain-Huerta, and Llorente-Isidro 2006; Peters 2008; Rodríguez and Delgado 2006; Universidad Nacional de Colombia 2010, 2011).

A first methodology has been developed starting from very useful historical data, since it allowed the initial recognizance of the zones affected by floods based on real data of past events. This methodology was implemented in five stages: 1. Search and compilation of historical documents, 2. Social cartography, 3. Analysis, systematization, and classification of the information, 4. Interpretation and qualitative hierarchization of the information and 5. Statistical analysis of the flood events.

This methodology also allowed the planning of a second methodology called the elaboration of geomorphological cartography, as it reconstructed the area covered or the stage reached by the water during a flood through the interpretation of the marks on artificial or natural elements (rocks and trees) along the river banks, acquiring historical documentation, other available databases, etc.

The methodology of the elaboration of geomorphological cartography was based especially on the use of evidence generated by the circulation of water over the flood-prone areas through a series of stages such as: 1. Multi-temporal analysis, 2. Collection of data, 3. Elaboration of a preliminary map of geomorphological units, 4. Validation in the field with the help of social cartography, 5. Regional and local analysis for the zonification of the threat, 5. Elaboration of a detailed map of geomorphological units and 6. Zonification of the threat with a qualitative and semi quantitative focus, assigning generic and relative degrees of dangerousness.

For the application of hydrological-hydraulic methods, the difficulty of the estimation of flood zones lies in the requirement of detailed information as a base, a DEM (Digital Elevation Model) of good resolution or in its replacement a very detailed topography and bathymetry of the zone as well as data of extreme streamflow.

Because our research focuses on small and medium sized urban centers where information is scarce and of bad quality, obtaining base information can be done through the extraction of indexes and parameters for a free access DEM such as the ASTER DEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer[1]) and seeking to define the relationships with the morphology of the zone and proposing the use of morphometric descriptors to define the morphology of the study zone using the HAND (High Altitude Nearest Drainage) according to the methodology proposed by (Nobre et al. 2011) and now analyzed in the research project "Methodological Proposal For Estimating Flood Zones With Scarce Information Through Geomorphic Descriptors Derived From DEM".

The HAND is used as a key descriptor for the zonification of flood areas through a variation in its input parameters, where the DEM must ensure a consistent flow directions with drainage network, to then derive flood zones through a proposed energy line in the drainage network and following these steps (Universidad Nacional de Colombia, 2010): 1. Description of the study zones in its hydrological and morphological aspects, 2. Collection of preliminary information, 3. Analysis of the frequency of maximum events (levels and streamflow) using probability functions (Normal, Log-Normal and Gumbel) with return periods of 2.33, 10, 20, 25, 50, 100, 500 and 1000 years, 5. Processing of the DTM (Digital Terrain Model): correction for clouds and sinks, 6. Generation of the maps derived from the DTM (fill, direction, accumulation), 7. Generation of the drainage networks (threshold vs. drainage density), 8. Application of the HAND starting from an algorithm of the following input parameters: map of the digital elevation, map of drainage directions, map of drainage network, map of fixed level stations or unfixed level stations, 9. Generation of the flood zones for the different threat levels (low, medium, and high) and 10. Validation of the results through the use of remote sensor imagery of the flood zones and those obtained with the hydraulic model HEC-RAS (Hydrologic Engineering Centers River Analysis System) and LIDAR topography (Light Detection and Ranging o Laser Imaging Detection and Ranging) available for the El Plato Municipality Case (Magdalena).

[1] http://asterweb.jpl.nasa.gov/

2.3 Evaluation of vulnerability

The growing impact of disasters has caused the need to improve the understanding of vulnerability, and therefore improve the quality of data and information management. The objective of vulnerability analysis is to know, study, and anticipate the susceptibility of a system or society to be damaged or affected as a consequence of a disaster. Several points of view on the understanding of the concept were analyzed in this research, given by experts such as (Bankoff 2003; Birkmann 2006; Blaikie et al. 1996; Cardona 2001; Cutter, Boruff, and Shirley 2003; Turner et al. 2003), and adopting Turner´s vulnerability model, which includes elements of sustainability, which in turn provides tools for land use management and decision making, including aspects such as the regulation of zoning, tendencies in urbanization, and scenarios of land use.

The process of vulnerability assessment has been started for the Caucasia Municipality, where there is a complete cadastral database with its respective maps in scale 1:2000 and an orthophotography from year 2012. Past flood events have been reconstructed with the historical and geomorphological methods, which through research-action techniques, review of existing databases and document sources, interviews of different institutional and community interest groups, leads us to state that the neighborhoods of La Playa, La Esperanza, and La Victoria are the locations that are most frequently affected by floods, since there have been at least 16 events in these places according to the database "Inventory of Disasters in Antioquia-DAPARD" (Corporación OSSO 2013) and 7 in the database of the (Unidad Nacional de Gestión del Riesgo 2013)

This will allow the design of the most detailed transects for the application of a second data collection stage foreseen for May 2014, which will be conducted through an already established survey in the zones that have been identified as floodable. The collection of georeferenced data about infrastructure, dwellings, buildings, social, economic, and environmental aspects of its inhabitants is expected, as well as data on the impact caused by floods, first hand information to continue with a third stage of global vulnerability factor analysis, as well as to take advantage of the moment to infer about the speed of the flow for threat assessment.

The same work will seek to make an approximation to the mapping of social indicators taking advantage of the information collected and stored in the Identification System of Potential Beneficiaries of Social Programs-SISBÉN, which could yield a micro-scale analysis as a fourth stage that will also allow the construction of a global vulnerability index adapted to the Turner model and the construction of the corresponding vulnerability maps.

2.4 Evaluation of risk

In the subject of risk evaluation, there have been advances in the construction of methodologies, some of which are the RADIUS, SERGISAI, Risk-UE, DIANE- CM, SUFRI, FLOODsite, DISFLOOD in Europe and the HAZUS® program and CAPRA Model in the Americas (Botero 2009; CAPRA 2013; Escuder-Bueno et al. 2012; Morris and Samuels 2006; Morris, M.W., Samuels 2004).

It is of utmost importance to evaluate what is the true dimension of the problem and to determine the levels of risk we face, the consequences that these might have in the development of the community, and the actions that are required for its reduction. This evaluation becomes a dynamic and continuous process which must permanently adapt, hence the importance of developing an adequate territorial information system. For the estimation of risk, it is proposed to conduct a superposition of the vulnerability maps with the high and medium threat obtained. This superposition must be applied with the following scheme (Figure 2).

The **high risk** is a product of the occurrence of a high threat in high vulnerability conditions, which represent the loss of life and goods, affectation of protected areas and/or interruption of environmental goods and services, damages of infrastructure and productive activities that are unrecoverable and irreversible. In addition, they require priority attention in the short term, high disponibility of resources and intensive monitoring.

Vulnerability	Threat	
	Alta	Media
High	High risk	Medium risk
Medium	Medium risk	Medium risk
Low	Low risk	Low risk
None	No risk	No risk

Figure 2: Scoring of risk

For its part, **moderate risk,** resulting of a combination of high threat and medium vulnerability or medium threat and high vulnerability, generates high intensity consequences for health and loss of goods. Likewise, moderate risk implies the affectation of ecosystems for productivity and damages of productive activities and infrastructure in the medium and short term. They also require more priority and reach, a larger availability of resources and monitoring.

Low risk refers to the probability of partial losses of goods, affectation of ecosystems of lesser ecologic importance and damages of productive activities that can be recovered in the short term. They are also those of the lowest priority, reach, and allotment of resources.

The resulting risk maps will be followed by the design of risk scenarios according to dimension, for the different type of players, for the response to emergencies, for mitigation, for development planning and land use management and the adaptation according to the specificities of each one of the case studies.

3. DATA

The following are considered as inputs for the determination of the thread of flood through the different proposed methods:

- Spatial data: topographical maps (from Instituto Geográfico Agustín Codazzi-IGAC) at a scale of 1:25000 or greater, existing flood maps scale 1:500000, 1:100000 or higher, orthophotos and satellite images obtained by other high resolution sensors, DEM, geometry of riverbeds, map of fixed or unfixed level stations, cadastral map.

- Hydrometeorological data: Hydrometeorological precipitation series, volume and level series, records of water levels and volumes.

- Data on physical environment and landscape: geomorphological map.

- Data from the community or other sources. Information about the height of the water surface, historical databases of floods and their impact.

The following are considered as inputs for the determination of vulnerability:

- Socioeconomic data obtained in the field through the application of surveys and those contained in the Identification System-SISBÉN.

- The physical-spatial data of the dwellings that are in the cadastral database of each municipality.

4. RESULTS

Three maps have been produced to date for the evaluation of threats through the historical-geomorphological methods. These contain the flood areas associated to the different periods of return to be contrasted in the field and validate their potential.

With the results of the HAND method, a grade of threat (low, medium, or high) was assigned according to the criteria in Figure 3 in the following manner (Vélez et al. 2003):

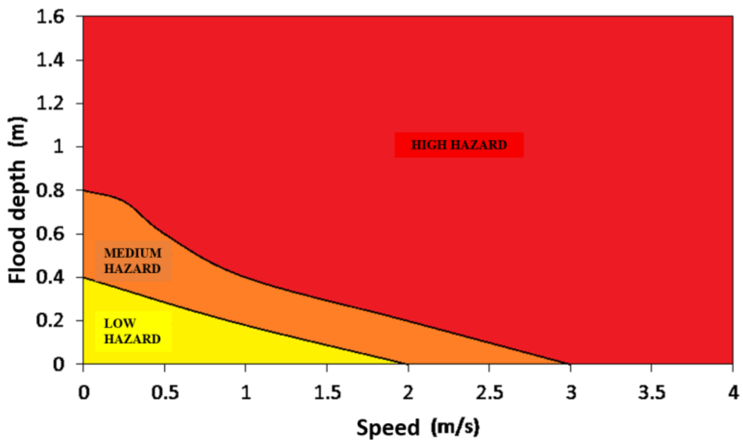

Figure 3: Criteria for the threat determination

Figure 4. shows the resulting maps from the application of the methodology for the zone of the urban center of the Plato (Magdalena) municipality.

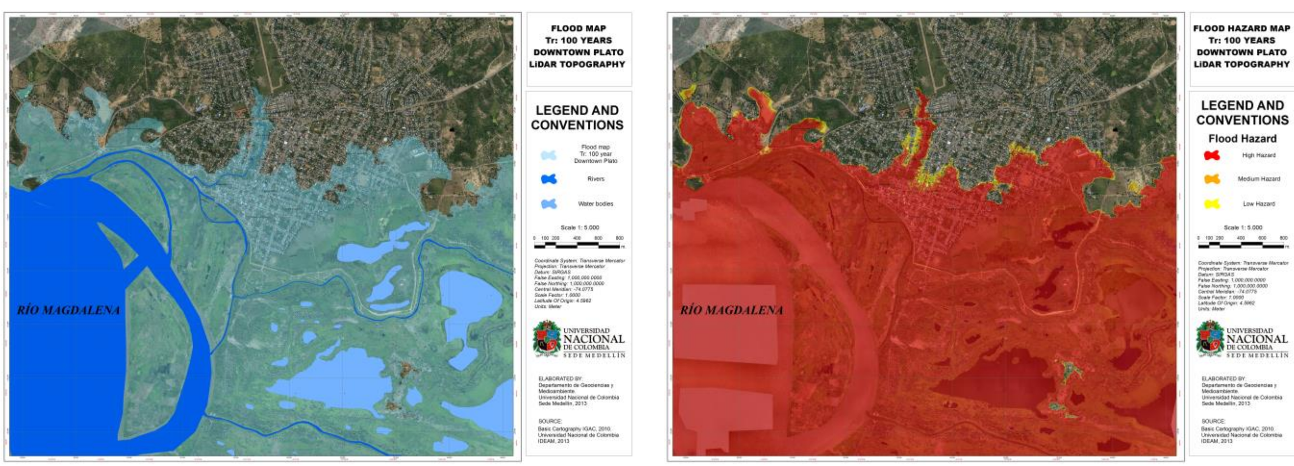

Figure 4. Flood and threat maps for a return period of 100 years in the urban center of the Municipality of Plato (Magdalena)

Figure 5. shows the flood maps for a return period of 20 years produced with the ASTER DEM and the DEM obtained from the LIDAR Topography with a 50 centimeter pixel size, which was possible to obtain from the "Zoning Project for the Threat of Flooding in 10 Municipalities of the Colombian Territory" conducted by the Universidad Nacional de Colombia, Sede Medellín for Instituto de Hidrología

Meteorología y Estudios Ambientales-IDEAM (Universidad Nacional de Colombia 2011), and which resulted in very similar results. For the first one there is a small overestimation of flooding in zones where there are small drainage networks (like ditches and small creeks), an expected result due to the 30 meter resolution of the ASTER DEM, which cannot correctly describe the behavior of the energy line in small networks, since the width cannot be represented in its scale. All the resulting maps were validated in the field with the communities, giving quite satisfactory results.

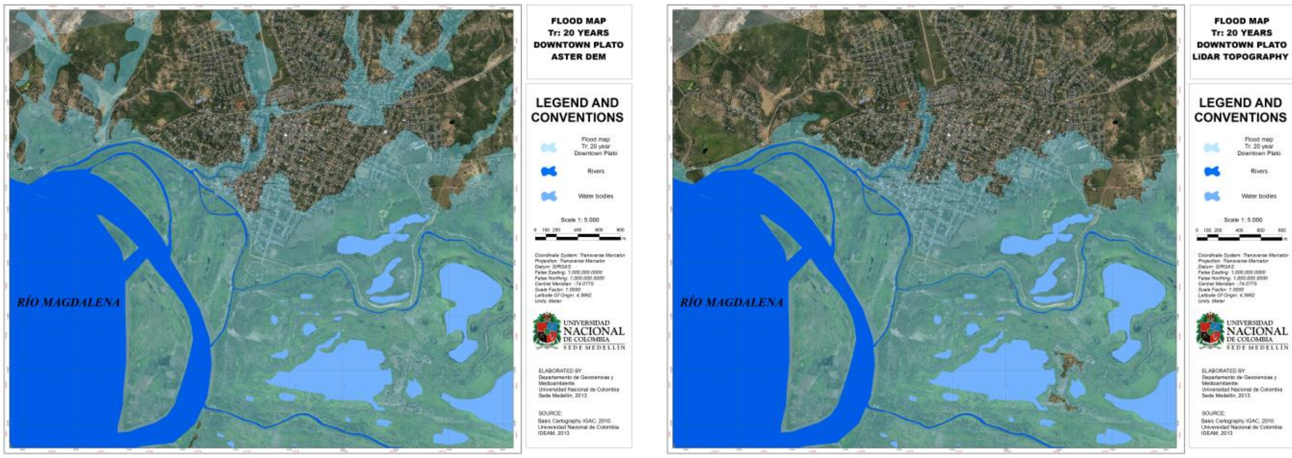

Figure 5. Flood maps for a return period of 20 years in the urban center of the Plato Municipality (Magdalena) obtained through ASTER DEM and with LIDAR Topography

To obtain the products of the evaluation of the vulnerability, the corresponding values from the vulnerability index (low, medium, and high vulnerability) will be assigned through work using the GIS technology, which allows the assignment of colors for a better setting and visualization of the analysis of these vulnerability maps and further crossing with the threat variable for the risk analysis.

The products of risk evaluation are the maps of high, moderate, low, and no risk, resulting from the superposition using GIS technology, equally for setting and visualization of these risk maps.

The resulting maps for the risk evaluation can be used to make decisions when it is time to make a review and adjustment of the land management use of the municipality, since they generate conditionals to land use that can be applied to the regulation of land use, in the design and implementation of physical measures and flood risk management policy instruments, etc., contributing to the reduction of existing risks and to not permitting the generation of new risk conditions.

5. CONCLUSIONS

Colombia has a lot of knowledge to develop and strengthen, especially at the regional and local level, about its local realities and the zones that are at risk (Secretaría Interinstitucional de la Estrategia Internacional para la Reducción de Desastres 2004). Despite the fact that the importance of the reduction of risk of disaster is being increasingly understood and recognized and that the response media have increased, disasters, and in particular the management and reduction of risk, continue to represent a great challenge for the country and the whole world.

The risk management and its incorporation to land use management and the planning of local development should be a given as an instrument to avoid the generation of new risks. However, there are no methodologies or standards for it, therefore the importance of incorporating the complex analysis of risks from the necessities and vulnerability of each region, seen as a benefit and not something imposed (Dirección de Gestión del Riesgo 2010; Dirección Nacional de Planeación 2005).

The methodological tools that have been presented here, have allowed until now to evidence that it is possible to adapt to the level of available information about the conditions of threat and vulnerability of communities that reside in small and medium sized urban centers. In addition, it is also primordial to integrate the knowledge of its inhabitants, since they help evidence the present situation and widen the information that can be found at a local level, of what has been done, what can be done, and what should be done to prevent the occurrence of new floods, or to have more effective answers. Likewise, it serves as a strategy to reduce uncertainty and endow communities with the necessary ability to reduce risk.

There is in the literature a wide list of proposed methodologies for the zoning of flood risk, such as: historical methods, historical-statistic, paleo-hydrology, geologic-geomorphologic, historical-geomorphological, hydrologic, hydraulic, and remote sensor and SIG assisted. Each one of these methodologies present their limitations, as they differ in the different types of floods, types and treatment of information, the development of models and the acquisition of precise data, especially topographic, which can suppose a large economic and unfortunately non viable investment for a study in the regional or local scope of our country.

It is why there are advantages to proposing a methodology that is developed from historical data, as it can encompass a larger period of time to that registered by other types of methodologies such as the hydrometeorological, and in addition can yield information about dangerousness through the evaluation of the impact produced by a flood and its extension and about flood frequency. It is also combinable with methodologies such as those of hydraulic type, as they can yield data on the depth of a flood, making it possible to associate those heights with flows for the assignment of a specific probability and allowing the identification of needs in the future as related to the capture, collection, and standardized processing of the necessary information, which could be to make up a deficit in the same, improve the precision of the data or obtain more data with better detail.

About vulnerability, its degree of knowledge depends in a great measure of the amount and quantity of the available information, we have blanks in information and methods that allow integral evaluations of vulnerability in relation to the different dimensions of development. For example, aspects such as gender are rarely considered, the same as with exposure and perception that communities that are involved in this research. The proposal to generate a vulnerability index and its associated indicators, seeks to simplify and understand a situation that is experienced in a specific study zone and that should be known to improve the analysis of risk. Another advantage that these indicators present is that they can be evaluated and monitored in time and be analyzed in a regional scale, being of great usefulness to regional and international interest groups.

It is important to point that a risk analysis depends directly on the quality of the existing information and the existing situation at the moment of implementing such analysis and the available resources. If the available information is scarce and not reliable and the resources for the collection of information are limited, then the uncertainty about the final results will be very high. If, on the contrary, the information is in good condition of quantity and quality and there are resources for the extraction of the necessary information, then it will be possible to make an adequate evaluation and there will be high reliability in the decision making and the future results of the proposed actions.

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